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RF Emulator Network channel emulator for aeronautical telemetry testing

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Objectives and the journey

Our solution - RFnest™

System Design

Use cases

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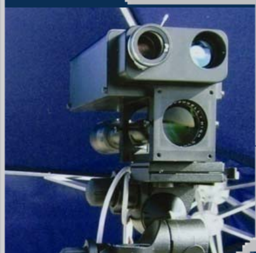

RFnest™: RADIO FREQUENCY NETWORK EMULATOR SIMULATOR TOOL

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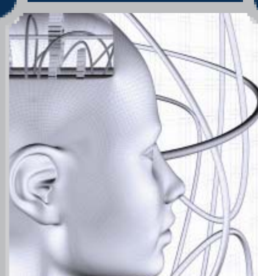

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Outline

- Objectives and the journey
- Our solution - RFnest™
- System Design
- Use cases

Objective

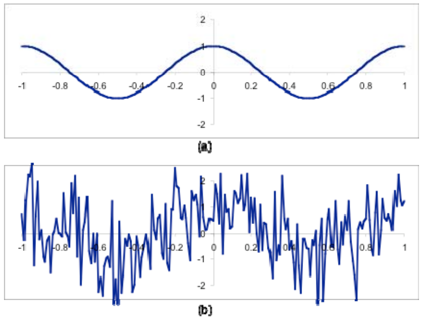
Realistic wireless network Test &Evaluation

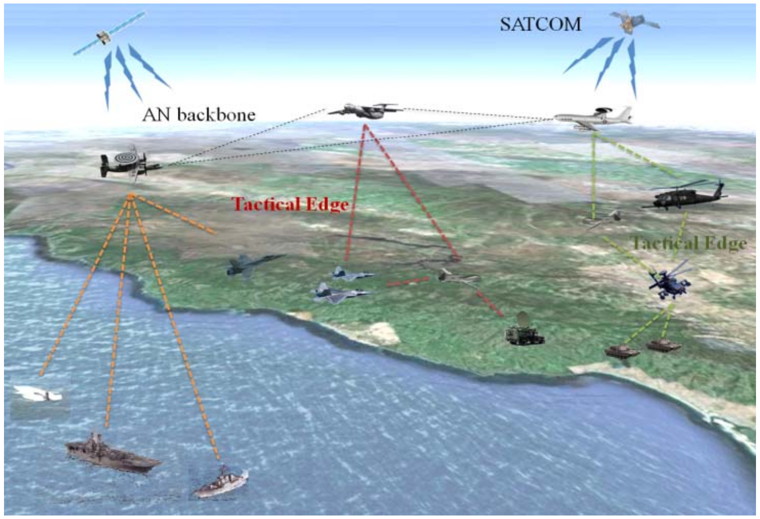
– Controllable & Repeatable

– With high-fidelity: it is wireless!

– Scalable

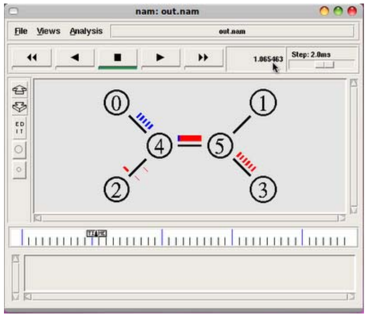
– Handling mobile scenarios



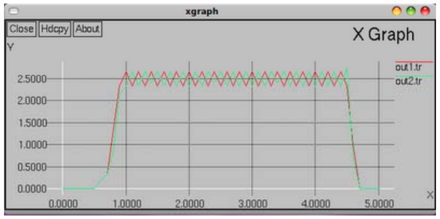


Journey - Simulation

- Scalable, available, easy to use
  - NS-2, OPNET, Qualnet, OMNeT++ …

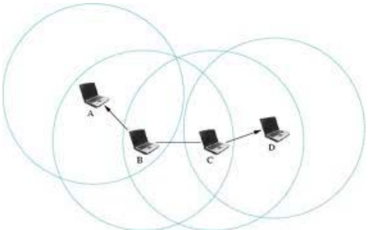


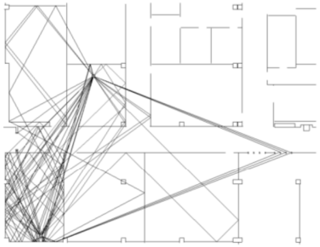
- Is my simulation realistic?
  - Of course! (“well, who cares ...”)



- Simulation: **scalable**, **controllable**, **repeatable**

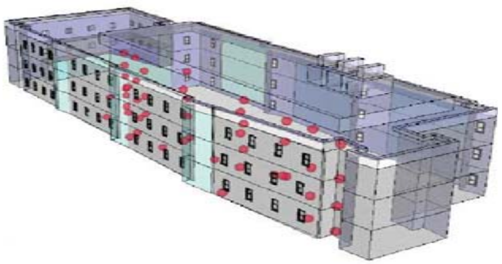
  fidelity: it depends …





Journey - Testbed

- Hardware-in-the-loop experiments
  - CORNET (Vtech), ORBIT (WINLAB), Emulab (U. Utah), …



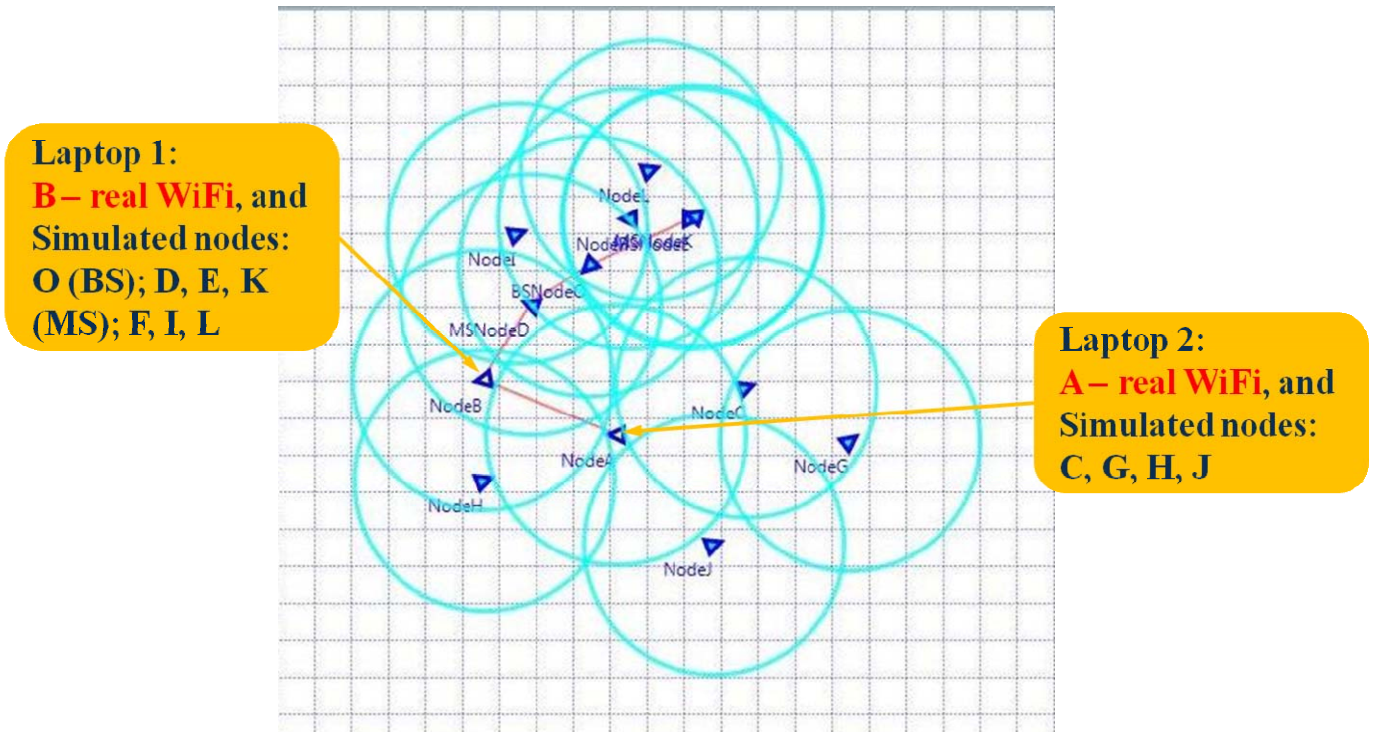
- Mostly static, fixed size topologies

- Can't fly testbeds

Journey - Mixed Mode

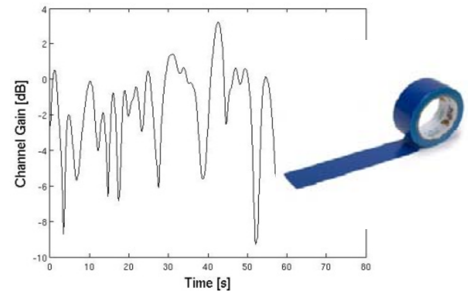
- Add **real** nodes in the **simulation**
  - To demonstrate real applications (e.g. video)

WiMAX Bridging



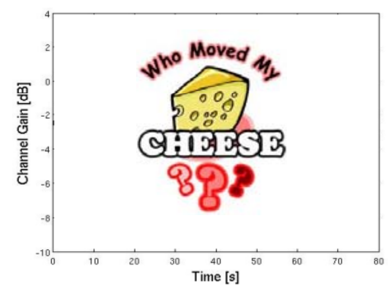
Journey - Field Test 1

- Walking in office hallways, laptops in hands



  – "Can you hear me now?"
  – "Great, let me blue-tape here …

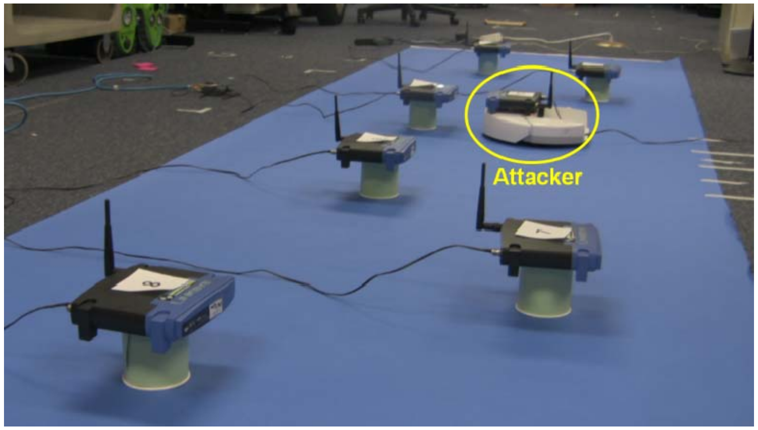
- In the morning …
  – "Can you STILL hear me?"
  – "I blue-taped it here, I swear!"

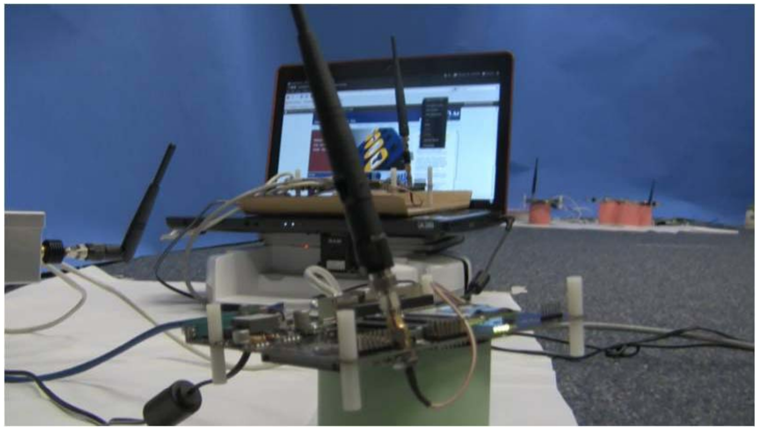


- Field test (office, parking lot …)
  – Not very controllable, repeatable, or scalable ("Good Luck!")

Journey - Field Test 2

- Not that bad, so we still do it, in our lab and at Forts





Journey - Airborne Networks

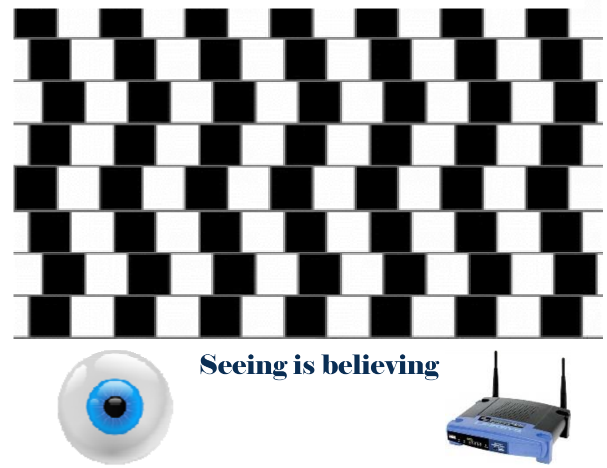
- We want to evaluate / demo on real hardware…
  - Don't want to go back to simulation

- But we can't fly any radio
  - And do it repeatedly & inexpensively

- Seems that we are stuck …

So How Can We Show AN Demo?

- So let us think about it …
- From the device's point of view
  - "Receiving is believing"
  - Everything else is real (demodulation, decoding, OS/network stack, application, etc.)



- Idea: Can we provide "correct" signal to the devices?
  - So that we can "fly them on the table"?

Agenda

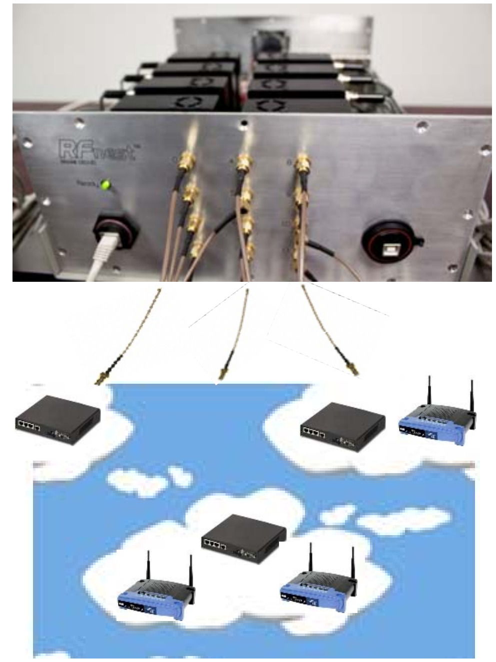
- Objectives and the journey
- **Our solution - RFnest™**
- System Design
- Use cases

RFnest™

- Radio Frequency Network Emulation and Simulation Tool (RFnest^{TM})
- RFnest provides "Air Environment" to devices via RF cables

RFnest Objective

- Real time wireless **network** emulator capable of providing realistic mobile network scenarios for stationary off the shelf **real** radios.



- **Hybrid** emulator where virtual nodes (to support scalability) fully interact with real HW nodes (to support high fidelity).
  - To achieve, need to make nodes (virtual and real) share the "**wireless feeling**"

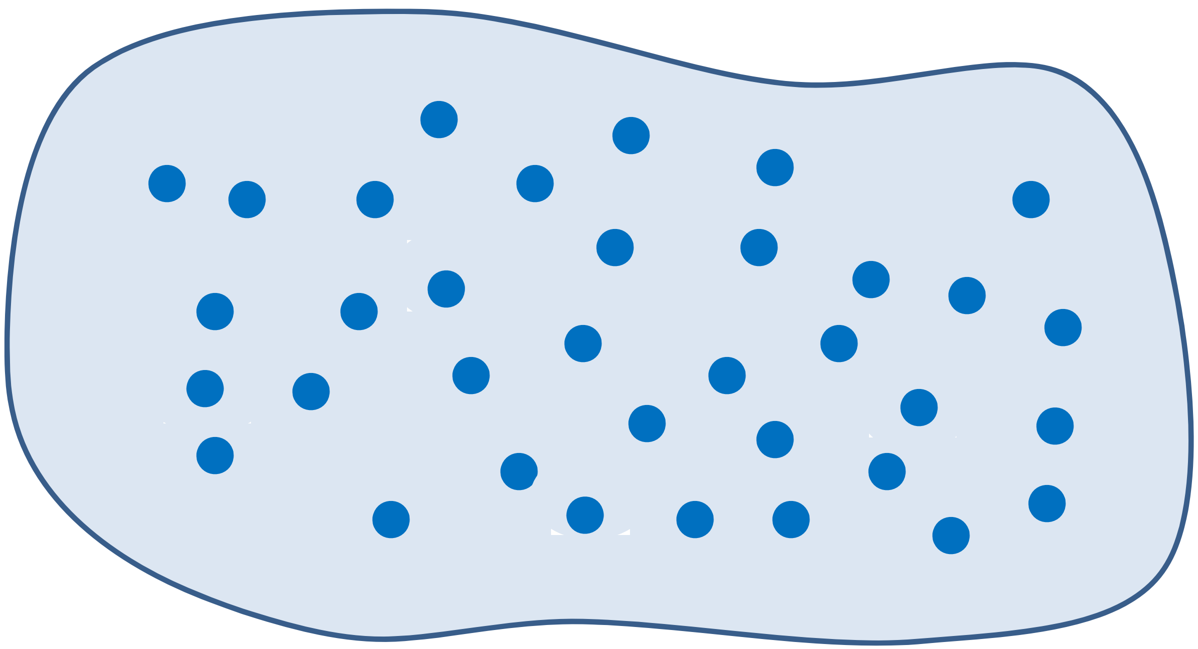
Gaps Filled and Benefits

- Realistic evaluation of new protocols using real radios

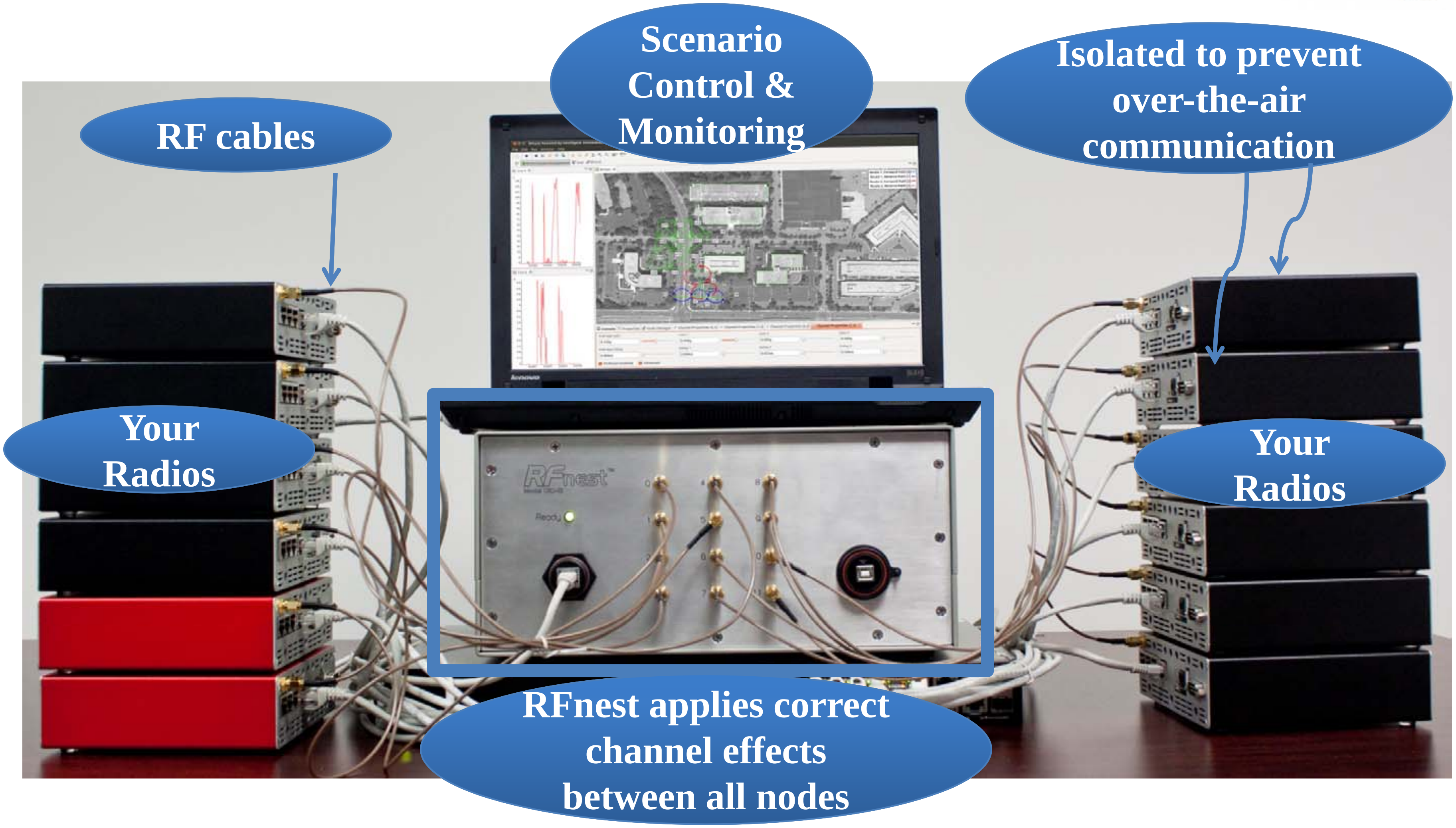
- Reduce cost and implementation time by:
  - allowing network evaluation in **controlled, repeatable, and realistic environment** with the same radio used in battlefield
  - employing a hybrid software/hardware network emulator to provide **scalability** as well as **high fidelity**
  - **replaying field tests** with all its complexity in a lab environment
  - **validating models** by creating identical scenarios for real radios and radio models
  - **collecting** and characterizing **wireless data**

Vision for Wireless Evaluation

- Mixture of real and virtual devices
- Tradeoff between scalability/cost and fidelity
- Real and virtual devices are “plugged in” to emulation
- Real and virtual interaction is as realistic as possible

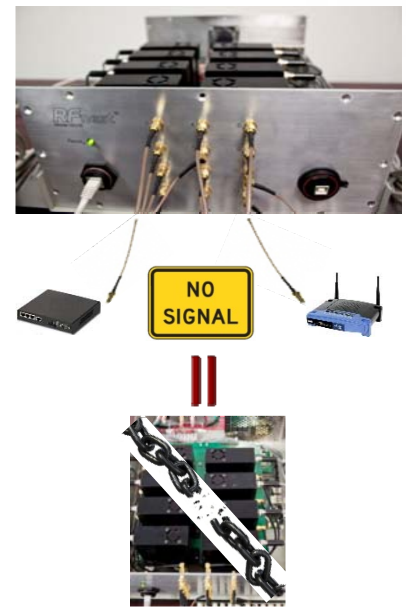


What does this look like?



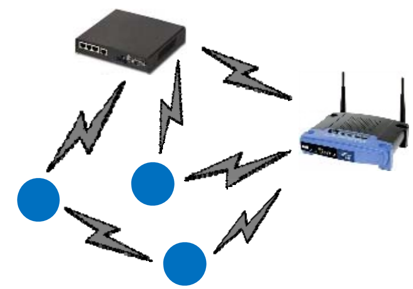
RFnest™ General Capabilities

- Real nodes with radios transmit over “emulated” channel
  - E.g, two “distant” nodes **do not** receive each other’s signals on their antennas



- Communication & interference over correct channels for a network of real wireless devices

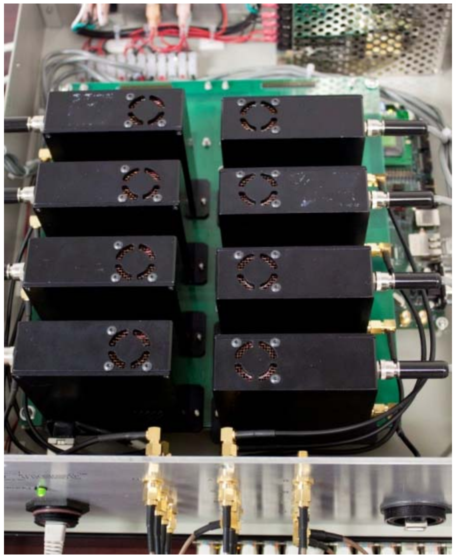
- Seamless integration of real (emulated) and virtual (simulated) nodes providing fidelity/scalability tradeoff

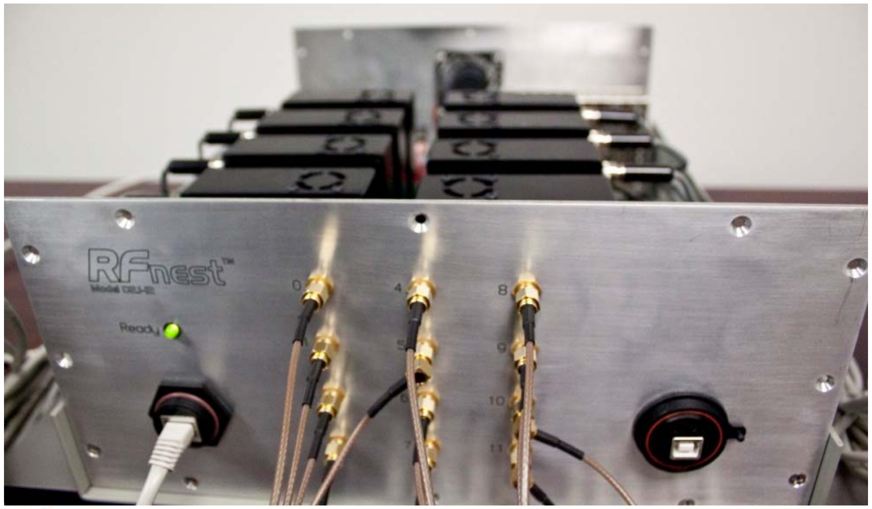


- **Done through FPGA based emulation hardware & accompanying software**

Status of FPGA based Digital RFnest™

- Currently have 8 and 12 node prototypes
- Integrated with Boeing CORE & NRL EMANE
  - 12 node (132 channel)
  - 2.4 GHz band, 20 MHz bandwidth
  - 2 to 3 taps per channel w/ separate gain
  - 0-100 us delay per link
  - Real-virtual interactions
- Designs for:
  - 225 MHz to 3 GHz
  - Doppler
  - More taps per channel
  - 24, 48, 96 nodes
  - Satellite delay

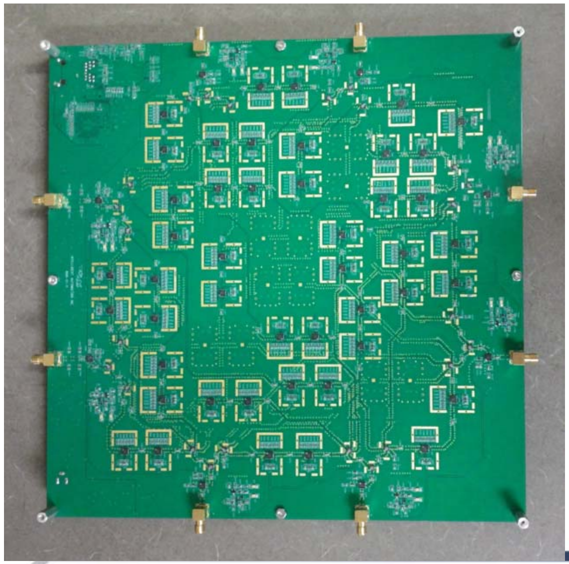




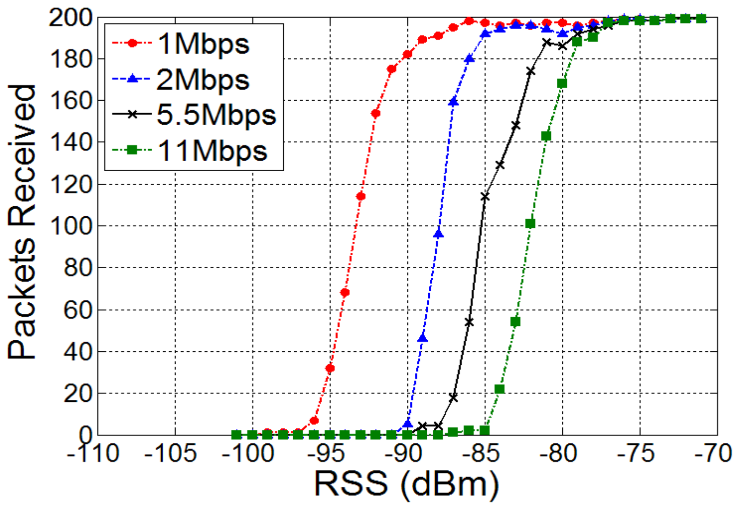
Analog RFnest™

- Controllable attenuator bank
- 0-63 dB @ ½ dB increments
- Wide band, arbitrary bandwidth
- 8 node single-PCB version currently in initial use
- Same control interface as digital

4 node

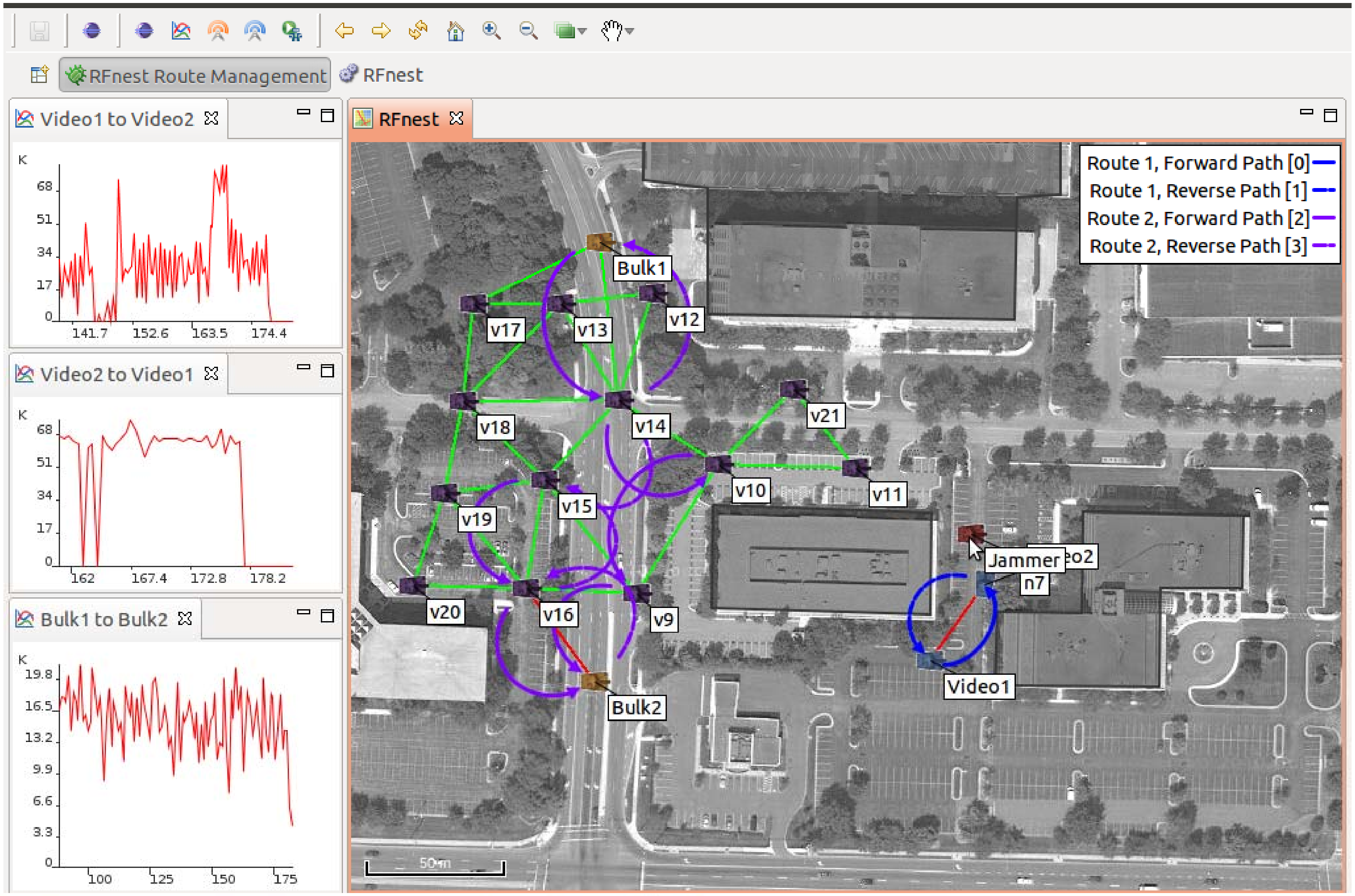


8 node



Integrated Scenario Control & Monitoring GUI

DCF-based node behavior, network status, channel state

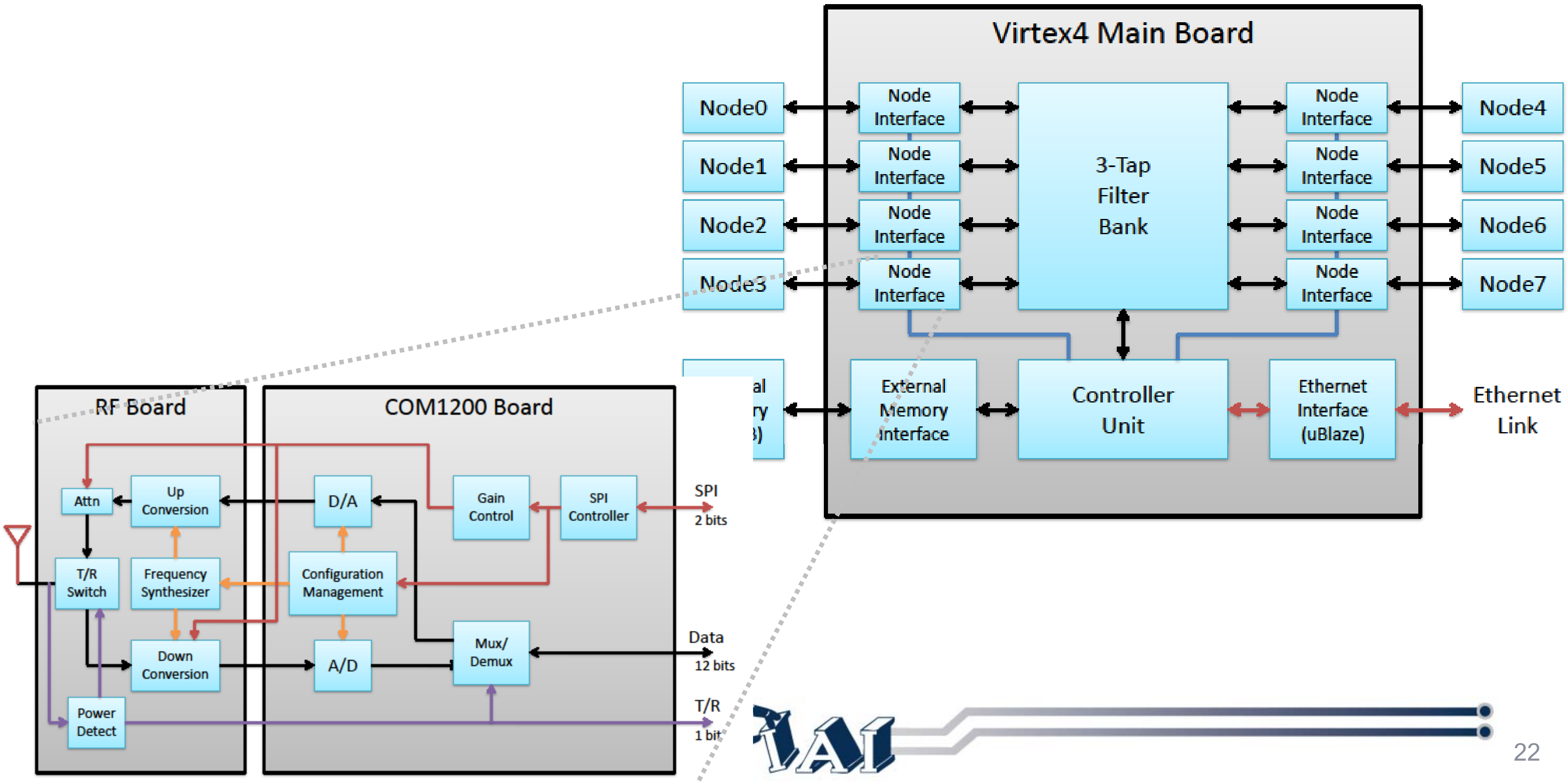


Agenda

- Objectives and the journey
- Our solution - RFnest™
- **System Design**
- Use cases

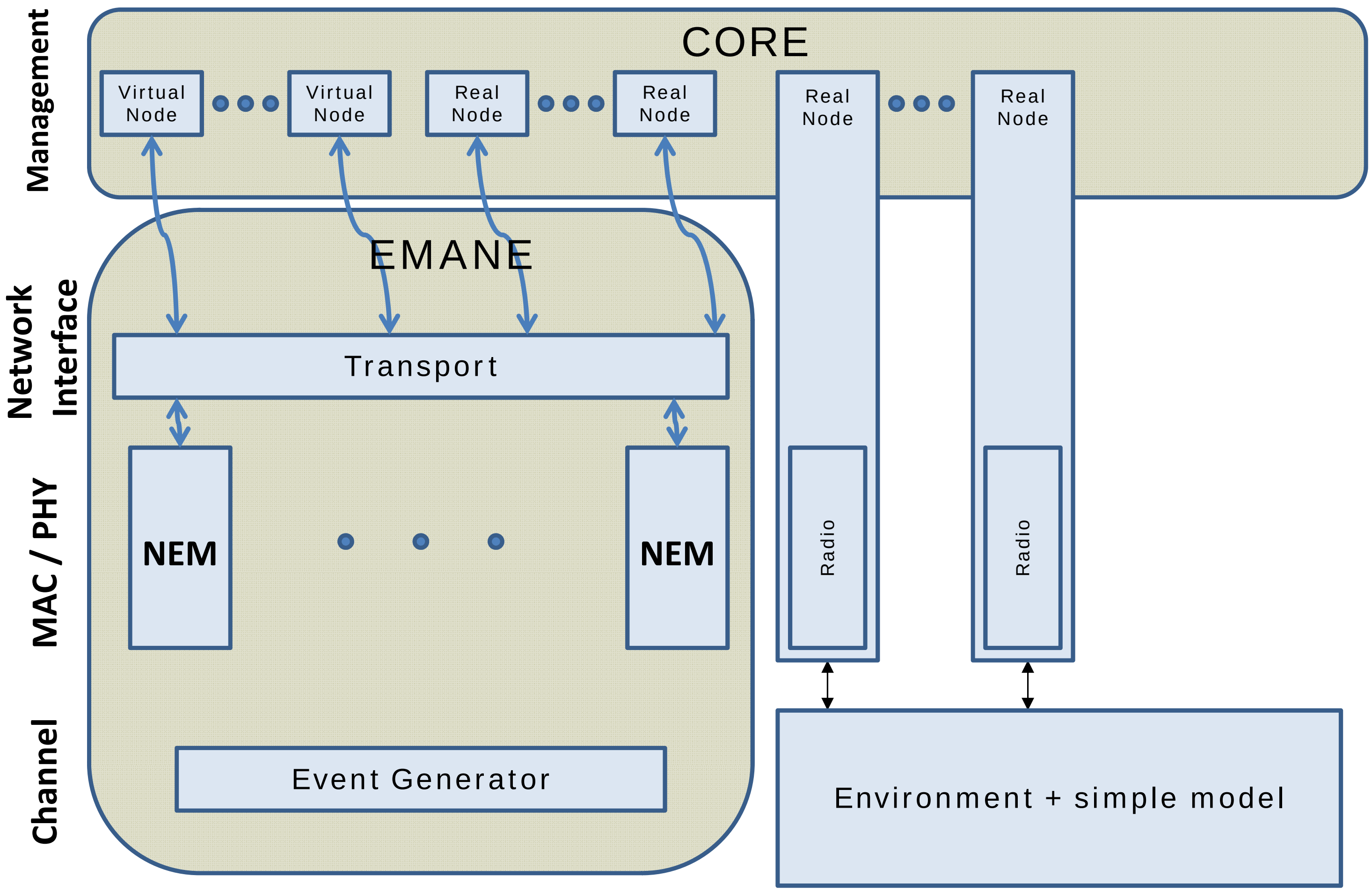
FPGA-Based Emulation Hardware

- RF Signals are digitally sampled, modified to reflect channel, then converted back to analog
- Allows channels with Doppler, multipath, delay, etc.

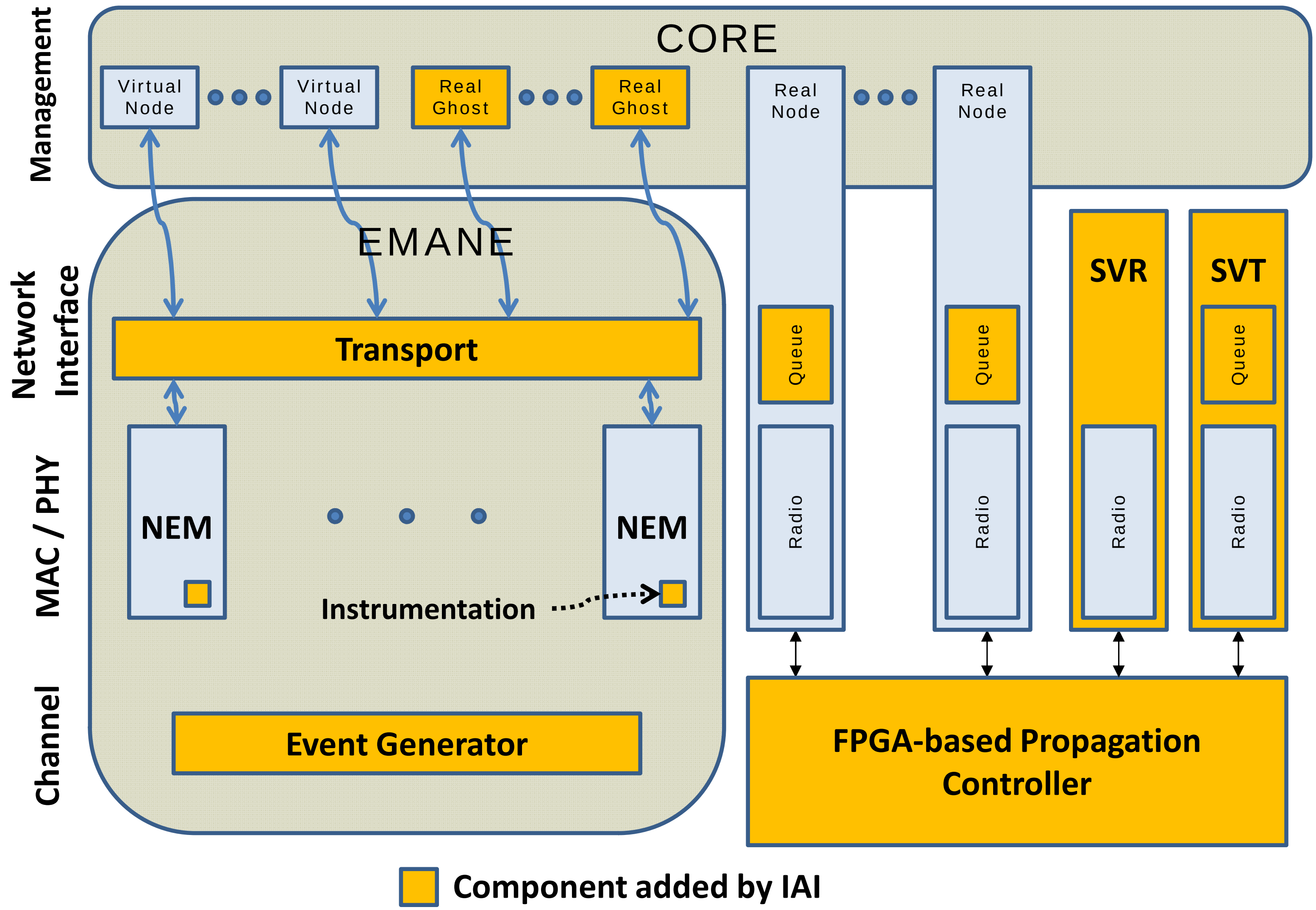


CORE & EMANE State of the Art

- Emulated nodes run a real OS (on either real or virtualized HW)
- Use **models** to determine whether packets are received
- Real and virtual worlds are separate



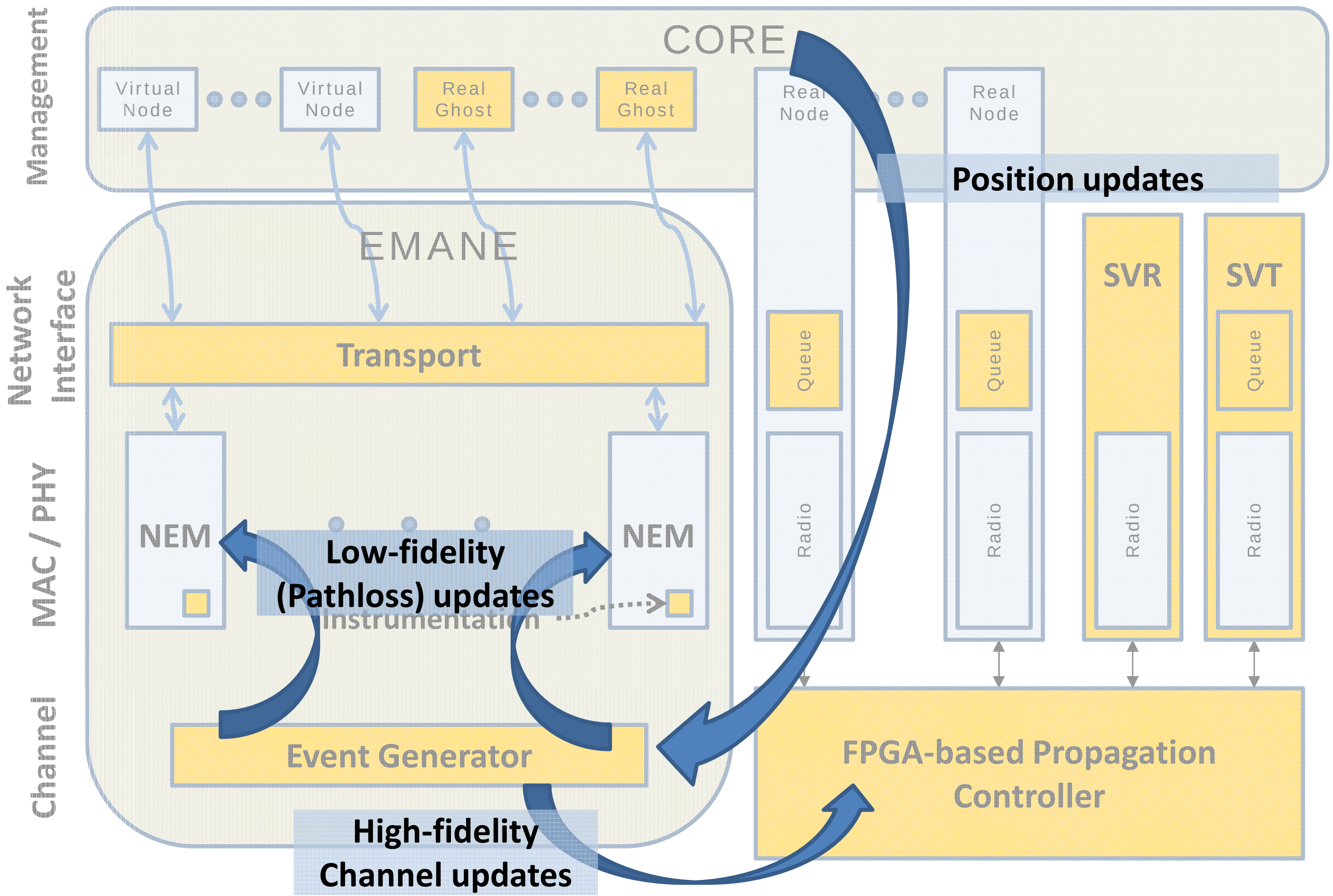
IAI's Emulation Architecture



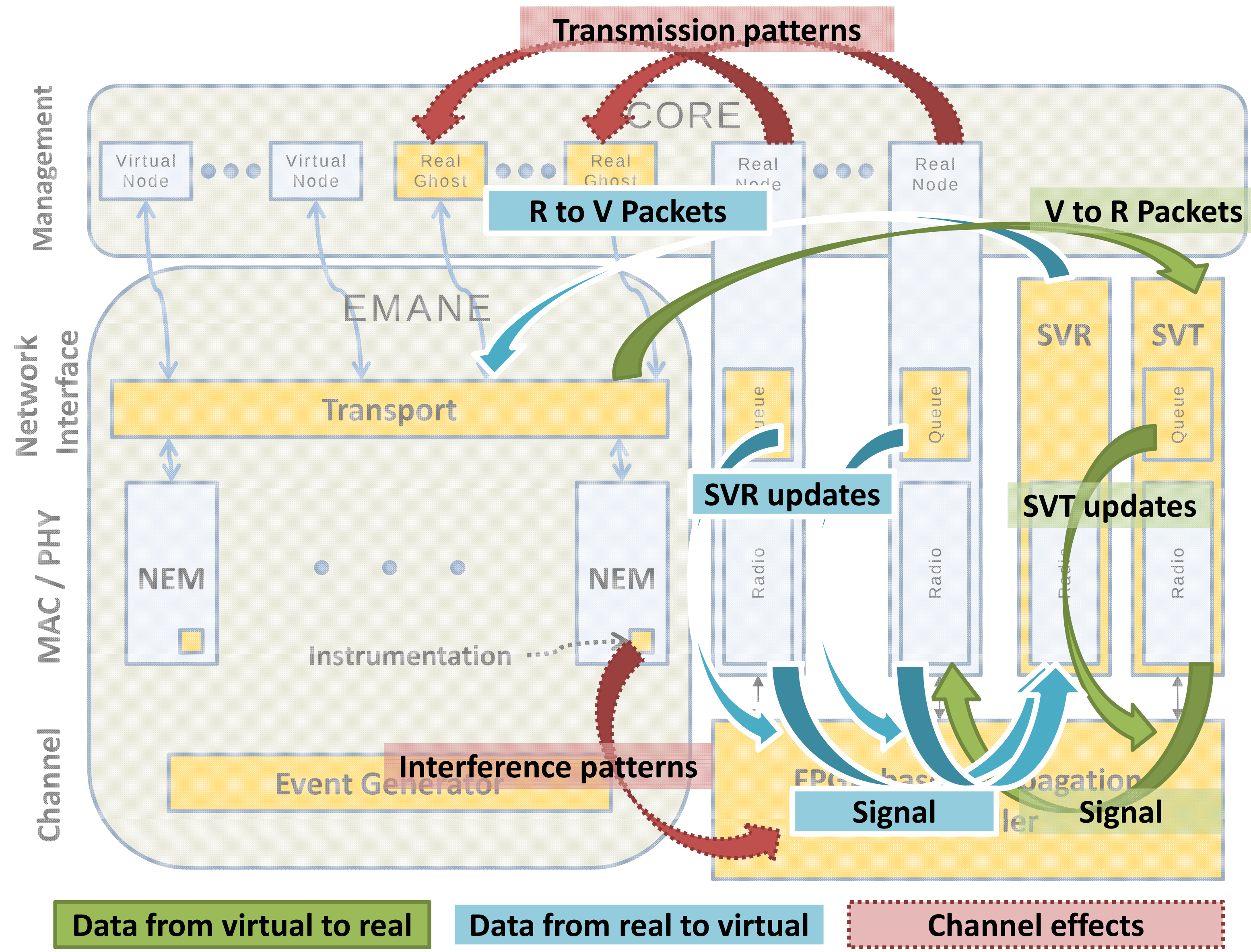
Real and Virtual Interaction

- Surrogate radios connect the real and virtual worlds
- Real nodes' radios receive packets from virtual nodes over appropriate channel
- Virtual nodes receive packets sent by real nodes' radios over appropriate channel
- Accurate interference effects being implemented

Channel Modeling



Seamless Use of Real / Virtual Nodes



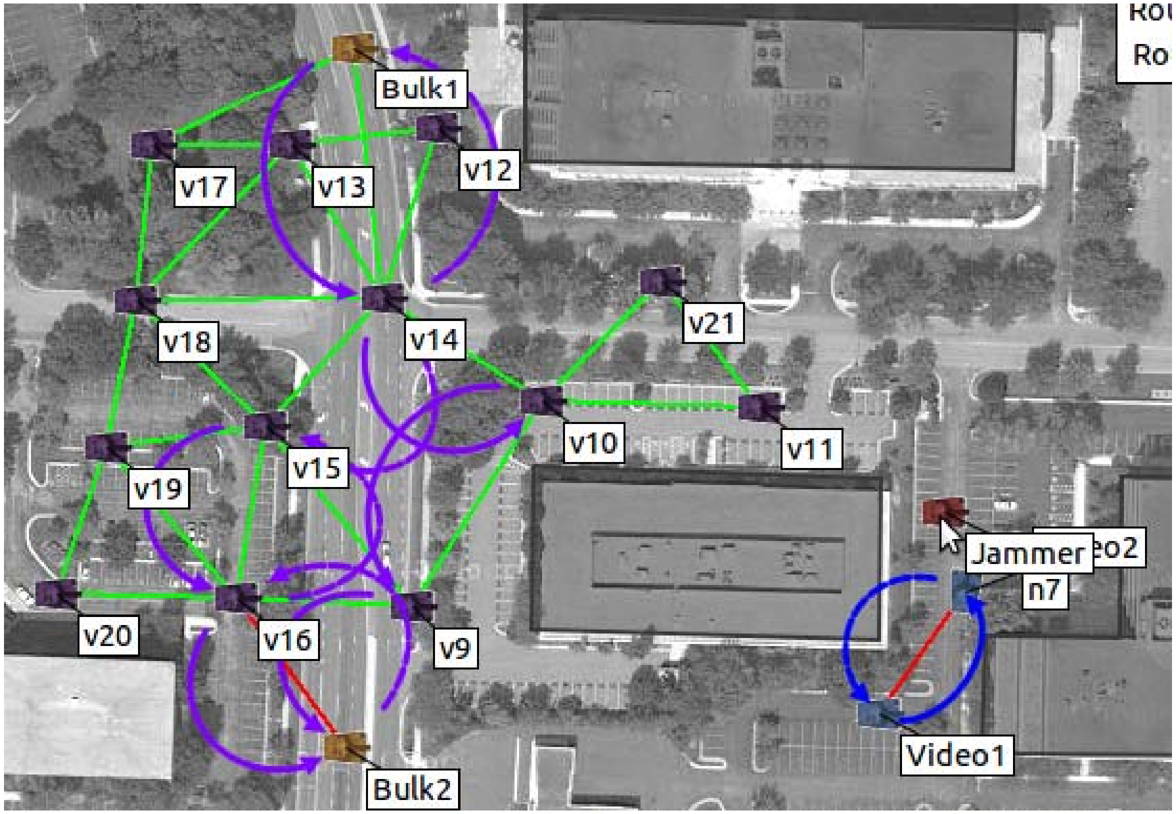
Real and Virtual Interaction

- Surrogate radios transparently connect the real and virtual worlds
- Surrogates' identities and channels change in sync

Surrogate
Radios
(SVR & SVT)

Real-Virtual Routing

- V-prefixed nodes are software-only with OS stack via CORE and radio via EMANE
- Other nodes are real devices (radios, jammers, etc.)
- All nodes (except jammer) run same routing protocol



Working with Virtual and Real Nodes

- Virtual nodes run **exact** same OS and software code, network stack, etc. as real radios
- OpenWRT toolchain allows user to switch between compilation for CORE/EMANE and creating firmware for real radios with a single configuration setting

Agenda

- Objectives and the journey
- Our solution - RFnest™
- Hardware Design
- Real-virtual Integration
- **Use cases**

Use Case - Model Validation

Does my model have same performance as reality?

Before:

- Compare performance of simulation and field test
- Maybe the performance is the same
- Maybe the performance is different
- Do my simulated and field test environments really match?
- How confident am I really?

Now with **RFnest™**:

- Create simulated environment
- Digitally create identical environment for real radios
- Performance comparison results are now reliable

Simulation becomes more reliable

Use Case – Field Tests

Scenario: a problem is observed during a field test

Before:

- Try to replicate in lab/simulation
- Fix problem in replicated scenario
- Test it in simulation
- Re-run field test, hope fix works **Time/$$$**

Now with **RFnest™**:

- Record field test scenario, reproduce with high fidelity
- Fix problem in field test scenario with field test radios (“let radios experience that again”)
- Digitally replay field test many times

<u>“free”</u>

- Run final field test with high confidence

Use Case – Protocol works according to model

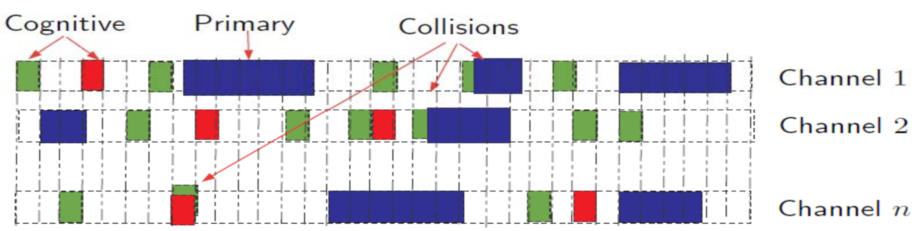
- Suppose evaluations using models (e.g. EMANE, ns-3, QualNet, etc.) suggest our protocol works fine

- Time for a field test ?

- RFnest™ serves as intermediate step before field test
  - Actual OS/network stack
  - Actual RF transmissions
  - Actual network behaviors
  - Only “the air” is artificial
  - <u>Validates the need for a field test and reduces the risk</u>

Use Case - Cognitive RF Evaluation

- Cognitive RF modeling “hole”
  - Multiple channels
  - Primary/secondary users
  - Sensing, measuring, timing
  - **Many degrees of freedom**



- SDR results in actual cognitive radios being ahead of model counterparts
  - “There is no model for my radio!”

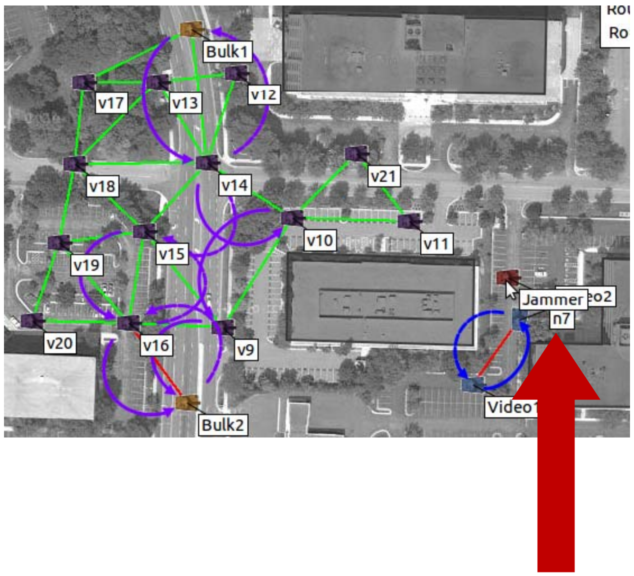
- Is the best path for cognitive radio evaluation to use

1) simulation, or 2) actual SDRs in an emulated environment?

Use Case - Jamming / EW

- Growing need to consider harsh RF environments
- Approvals for field tests with RF interference are difficult
- Infeasible to re-run field test many times to test performance in different RF conditions
- Fidelity of models for impact of various emitters?

- RFnest™ allows emitters to be added in the lab, signal is confined to RF cables

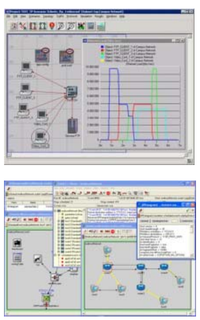


- If channel properties from field test are recorded, can efficiently re-run scenario with added emitters

Towards Realistic Wireless Evaluation

EMULATION

SIMULATION → REAL TESTING



network simulations

Emulator

“wireless wind tunnel”

RFnest

Repeatable field tests

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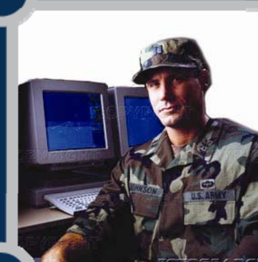
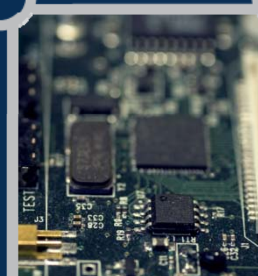
Innovative solutions to meet your technical challenges …..





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